DESIGN AND IMPLEMENTATION OF A GENERIC EXPERT SYSTEM TOOL FOR MACHINING PROCESSES

by

KRISHNAN. M
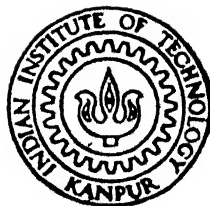
DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

JULY, 1990

DESIGN AND IMPLEMENTATION OF A GENERIC EXPERT SYSTEM TOOL FOR MACHINING PROCESSES

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

by

KRISHNAN. M

to the

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
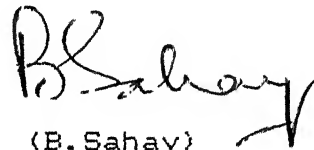
JULY, 1990

ME-1950-M-KRI-DES

CERTIFICATE

It is certified that the work contained in the thesis entitled **DESIGN AND IMPLEMENTATION OF A GENERIC EXPERT SYSTEM TOOL FOR MACHINING PROCESSES** , by M.Krishnan , has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

(J.L.Batra)

Professor,

Department of Mechanical Engg

Indian Institute of Technology

Kanpur.   208 016

(B.Sahay)

Professor,

Department of Mechanical Engg

Indian Institute Of Technology

Kanpur.   208 016.

July, 1990.

ABSTRACT

This work is a step towards computer aided process planning and automation. An attempt is made to develop a generic expert system which can accommodate various machining activities. Frames are used to represent the domain knowledge base while rules are used to represent various heuristic information that correlate the experimental data and mathematical models. For better memory management, provisions are made to compress the information in the form of simple rules in various frame slots. Using a parser, this rules are split up into relevant information. Knowledge base is arranged in a hierarchical structure for efficient searching.

The proposed system provides useful assistance to the user for developing expert systems in different machining processes like turning, milling and drilling. User can select the number of parameters to be considered. User has the facility to add more information to an existing knowledge base at a later stage; view and verify the existing knowledge base. There is no limitations to the number of parameters that can be selected or consulted.

An expert system for the turning operation of Super alloys is also developed using this work. User has the facility to consult for various critical parameters in the turning operation.

ACKNOWLEDGEMENTS

CONTENTS

CHAPTER

LIST OF FIGURES

LIST OF TABLES

LIST OF SOURCE PROGRAM FILES

SOURCE FILES	EXECUTABLE PROGRAM
MAIN. C	XSPERT. EXE
REAL. C	
EX. H	
MENU. H	
WINDOW. H	
REAL. H	

DEMO FILES

TURN. TLE

TURN. KB

TURN. DAT

CHAPTER.1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The use of computers in manufacturing operations has been growing rapidly. Computer application include inventory control, scheduling, machine monitoring and other information applications. These are the primary applications for transferring, interpreting, and keeping track of manufacturing data. Another promising area of computer application is in manufacturing processes. This technology present great economic benefits in improving manufacturing productivity.

Machining is one of the most important methods of removing unwanted material in the production of mechanical components. Metal cutting is an unusually complex process largely due to the fact that two basic operations occur simultaneously in close proximity with strong interaction, namely large strain plastic deformation in a zone of concentrated shear and the material transport along a heavily loaded region of tool_chip intersection.[1] Hence normally thumb rules are used for planning in most of the machining operations rather than the experimental

results or authenticated theories. Several simplified models which emphasise different aspects of the problem such as thermal, material and surface considerations are operative with varying degree of importance depending upon the specific machining conditions.[2,3]. Considerable difficulties are encountered to correlate these different models. Hence heuristic methods and approximations are used for even well known models like Taylor's model[4]. Industries started compiling machining data for different processes, suitable to their requirements and environment.

An average intelligent human being (a process planner) adopts these thumb rules and databases and assigns varied weightages to these inputs to arrive at his decisions. On the other hand, an intelligent system or expert system, which simulates a human expert, can perform this task in an efficient way. The problem solving approach of an expert system is explained in the next section.

1.1.1 EXPERT SYSTEMS

Expert systems are one among the most useful and interesting applications of the artificial intelligence. An expert system is a computer program that uses knowledge and inference techniques to solve problems that are usually solved with human expertise. An expert system stores a large body of facts, along with rules about

how these facts can be used to solve problems. Expert systems are characterised by the following facts. Firstly, they are knowledge intensive, that is, they use large amount of diverse input to produce small quantities of output. Secondly, they operate on symbols that represent facts, knowledge or objects rather than numeric or character data. Thirdly, they solve the problems using heuristics which are rule of thumb that makes rapid leap in reasoning , and they can function even if some input data are missing or inaccurate. Also unlike traditional programs expert systems can explain their reasoning.

An expert system can be used to solve problems that are unstructured and where no formal procedure for finding a solution exists. The expert system can use its internal knowledge and rules to formulate its own procedure based on the problem definition. The expert system is ideal for problems involving formal reasoning.

It is difficult to represent the actual characteristic of human expert in a computer program. The expert systems, often called knowledge based systems, are a class of computer programs that can emulate human expert over a limited domain of expertise. problem solving ability. The expert system has no real intelligence nor can it completely take the place of human expert. It can be used as a supplement to the human expert by giving useful advice.
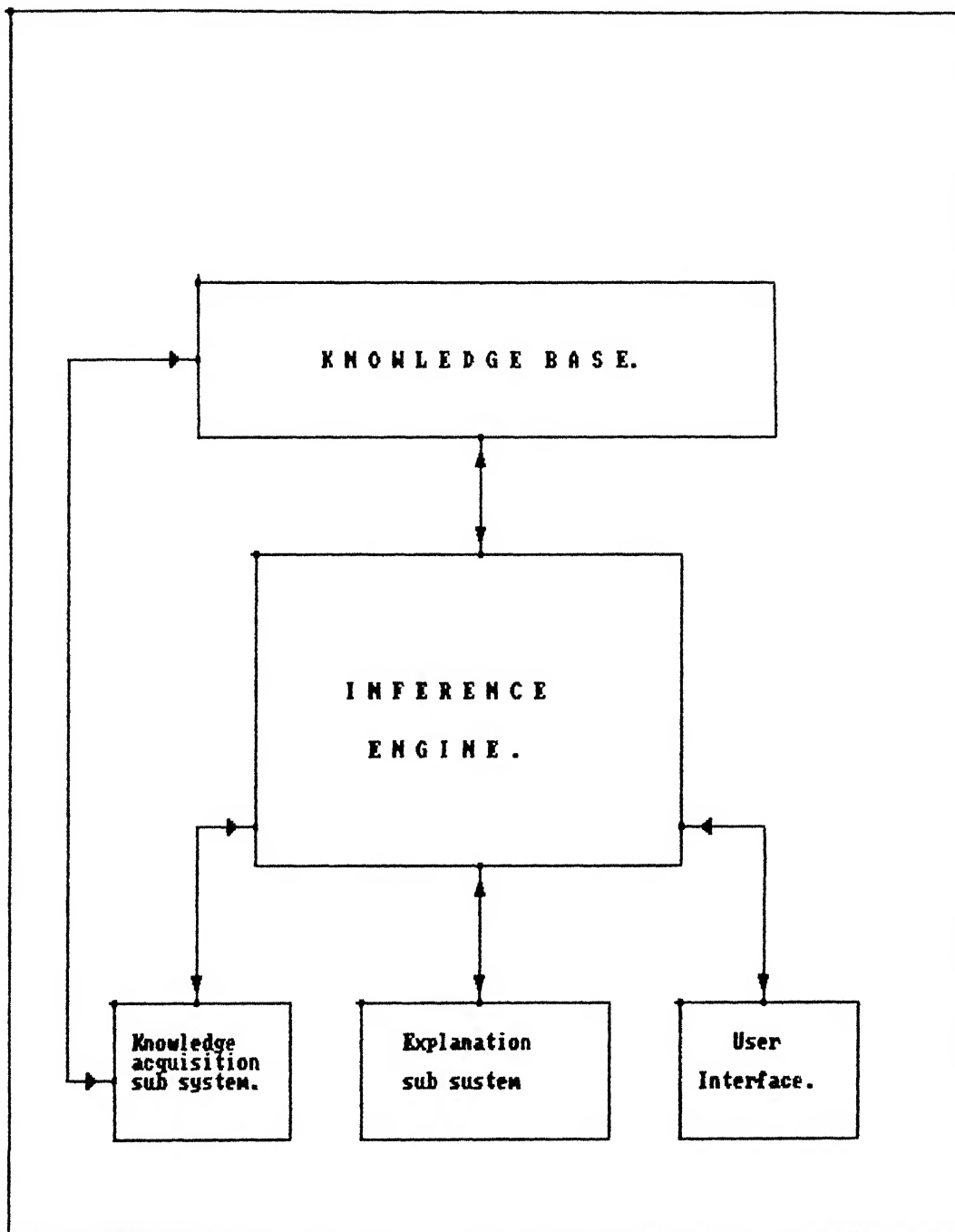
Fig. 1.1

Expert system architecture.

Expert systems have a number of advantages over human experts. Besides being able to make decisions in fractions of the time it normally takes for human experts, these systems raise the average performance of the human expert by incorporating the knowledge of more than one expert. Also expert systems can be duplicated allowing it to be cloned and placed on many systems and, thus ,become available to many users.

Expert systems are composed of an inference engine, a knowledge base, and some type of user interface. The inference engine is the main component of the expert system which controls the reasoning process. (Fig.1.1). The knowledge base contains the necessary knowledge stored in proper knowledge structure.

1.2. LITERATURE SURVEY

Effective correlation of mathematical models and heuristic methods is a major problem to be tackled in machining world. Most of the mathematical models developed for various machining operations like turning, milling, drilling are of empirical nature [5] .

Taylor suggested the Taylor's tool_life equation ,which correlates the cutting speed and tool life for single point cutting operations. Ernst and Merchant [6] suggested a model to

determine the cutting and feed forces in single point cutting operations using the Merchant's diagram. They proposed a shear plane model for cutting operation. Later Lee and Shafer [7] made some modifications to the Merchant's model with a better analysis of shear plane model.

Attempts were made to adopt these mathematical models to suit the industrial environment and practical conditions using expert systems.Majority of the expert systems in the area of machining were developed as the part of some computer aided process planning systems[8]. Most of them use optimisation procedures rather than heuristic methods to select the proper parameters.

Evershein [9] developed a system for optimisation and selection of proper cutting data using a database called INFOS. The system selects proper cutting parameters from the huge database and optimises them according to the required conditions like maximum depth of cutting, optimum tool life, optimum feed rate or optimum cutting speed.

Ginsti [10] developed an expert system, COATS for optimal tool selection for turning operation. COATS is a rule based system which can suggest a proper style of tool, tool holder, insert for a given material and operation. It has a rule manager for entering and deleting rules. It has self learning facility to add new rules to the system. COATS is implemented in PROLOG on VAX system.

Boerma [11] has developed an expert system called FIXES for selecting proper set_up and fixture for the machining operation. FIXES is also controlled by rules, which selects the proper holding method and fixture for a particular component. FIXES selects the support surface, positioning face and clamping face. It selects the clamping face by verifying the strength of the surface and size of the clamps and the face.

XPLANE [12] developed by Van't Evve et al, is basically a generative computer aided process planning software. An expert system is included in the system for selection of proper tool and the parameters. It is a rule based expert system with backward chaining inference engine. It has the facilities to add and delete rules and a simple explanation facility. The whole system is implemented in FORTRAN.

Anbarasu [13] developed an expert system, GREXP for surface grinding operation using both thumb rules and database. GREXP tries to correlate a number of parameters like grain size, grain type, work tensile strength, wheel speed, wheel diameter, surface finish and number of passes. GREXP is implemented in Turbo Prolog.

Srinivasa Rao [14] extended the GREXP for a wider range of grinding operations using the expert system shell Personal Consultant of Texas Instruments Inc. He has correlated

optimisation processes with the rule base of Personal Consultant.

Work piece burn was considered as the limiting factor in determining grinding parameters. A restriction on the value of the ratio of work speed to wheel speed was imposed for better surface finish. Memory overflow in the Personal Consultant environment was a major problem for this work also.

1.3.OBJECTIVES OF THE PRESENT WORK

In the present work an attempt is made to reduce the efforts in the development of expert systems for various machining operations. An expert system for machining should have the facility for on line and off line selection of various critical parameters. A review of the literature on expert systems on various machining operations suggested that it should be possible to evolve a common strategy for the development of expert systems for machining operations. In the present work, an expert system tool, called, XSPERT, is developed to facilitate the design of expert systems for various machining operations.

Various knowledge representation methods were evaluated to select a feasible technique. For details the reader may refer to Chapter 2 After comparing the pros and cons of various techniques, frame is selected to represent the knowledge base. Further, rules are also included to interlink various frames in different layers and to apply heuristics. The frames are structured in different

layers which are interconnected. Breadth_first strategy is selected for searching operation. Discrimination nets are designed for fast and and efficient searching. Provisions are made to use the expert system tool for the real time controlling of machining processes.

For better portability and wider usage, the present system is implemented on microcomputer. Microsoft C Version 5, running under DOS is selected as the programming language. Menus and windows are included extensively to make the system user friendly.

1.4. THESIS ORGANISATION

Chapter 2 deals with the the knowledge representation method, searching, heuristics, the analytical background and chalks out the procedures adopted for the proposed system.

In Chapter 3, the implementation details of the proposed system in Microsoft C with the algorithms are discussed.

The methodology adopted to develop the expert system for turning operation and solved problems are discussed in Chapter.4. A few examples are included to demonstrate the potential of the methodology.

Conclusions and limitations about the system are included in Chapter.5.

At the end of them, a user's manual is included as an appendix to guide the user in the use of the software.

CHAPTER 2

SYSTEM ANALYSIS AND DESIGN

In this chapter various methodologies adopted for the design of the expert system tool, XSPERT are discussed. Various parameters to be controlled and evaluated for different machining operations and their similarities are also discussed A detailed discussion about the knowledge representation methods and the heuristic methods to be used are made.

2.1. CLASSIFICATION OF MATERIAL REMOVAL OPERATIONS

The various material removal operations may be classified into the following categories mainly in terms of the size of the individual elements (chips) removed.

       Cutting

       Grinding

       special techniques like ECM and EDM

In normal cutting operations, individual elements or chips removed are relatively bigger in size compared to grinding
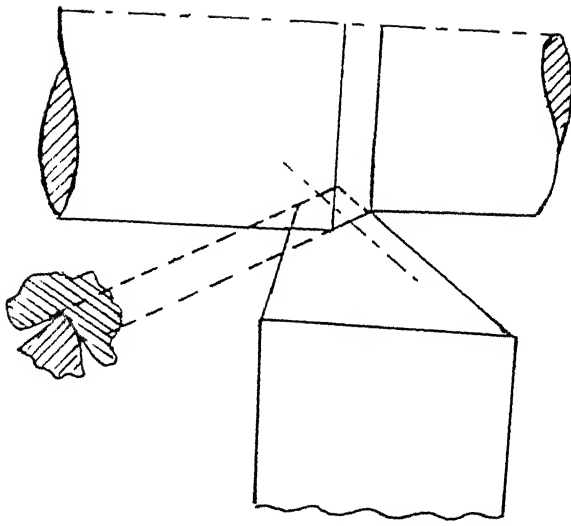
a Turning.
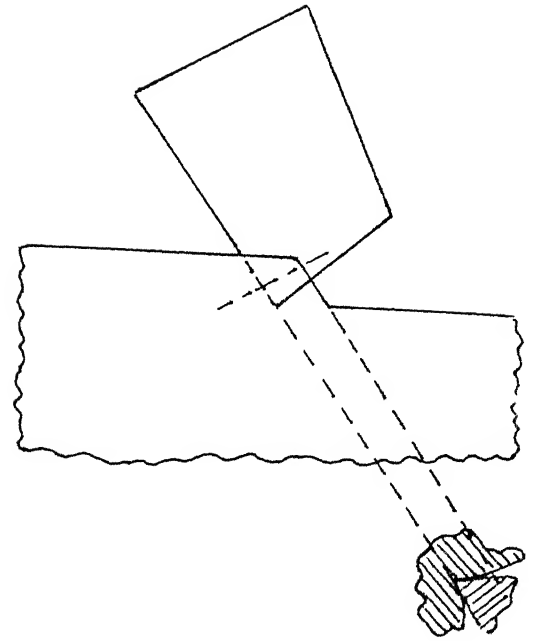
b Shaping
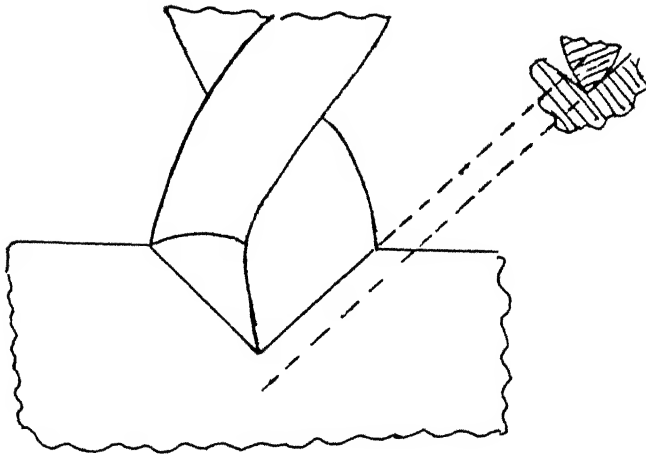
c. Drilling
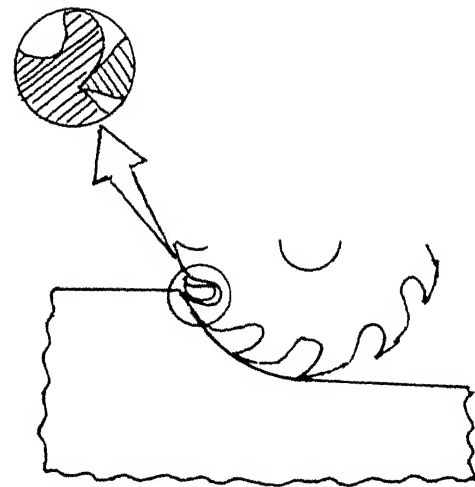
d. Milling

Fig. 2.1

Metal removal process in different machining processes

operation. In the case of grinding operation, individual elements are very small like dust particles. Special techniques like EDM and ECM produce the components by removing the excess material in a microscopic or minute level.

The cutting operations can be subdivided into following categories

Turning	Boring
Milling	Reaming
Drilling	Planing
Broaching	Threading

In these processes, turning,milling and drilling are the three most important and common cutting operations. Turning is the process of excess metal removal from a rotating work piece by moving a single point tool longitudinally. On the other hand, in milling operation, excess material is being removed by a rotating multi point tool over the stationary work piece. In the case of drilling operation, there is a relative rotary motion and a linear motion between the work piece and the tool. An examination of Figure 2.1 reveals that the cutting action by the tool in each case is very much similar. Hence various parameters that affect the cutting operations are also almost same. Some of the important factors that influence the performance of these cutting operations are discussed below.

Work material characteristics like

Hardness of the material

Heat treatment process undergone

Surface conditions (scales, inclusions etc)

are some of the factors that affect the cutting operation.

Tool material composition, hardness and tool geometry are also equally important in a cutting operation. As a thumb rule, tool material hardness should be at least three to four times higher than that of the work material for better performance. Various tool angles like rake angle, cutting angle and clearance angle will also influence the cutting operation.

Cutting parameters like cutting speed, feed rate, depth of cut are very important parameters and are closely related to most of the other factors mentioned above.

Other parameters which influence the cutting operation are type of coolant, rigidity of the machine, chatter and vibration.

Three common methods to select various parameters for different machining processes are given below.

Most common method is to select the parameters with the help of experienced process planner, foreman or machinist. Relying the experience and judgment of any individual is the least systematic approach and carries the greatest risk. The risk lies in the potential loss of the individual who has acquired the experience and judgment over many years. Personal judgment is also undesirable because it has no scientific foundation.

Second method is follow the hand book recommendations. This has some advantages than the previous method. Hand book recommendations are compiled from the experience of more than one person. Hand books of machinability data are generally developed from a systematic analysis of large quantities of machining data.

Hand book approach has got several drawbacks when applied to a particular industry's environment. First hand book recommendations tend to be conservative and the parameters suggested may be based on worst_case conditions. Second, the working environment, machine tools and conditions of the hand book may not be coinciding with the actual conditions in the industry. Third, the use hand book recommendation is not compatible with the over all philosophy of the automation of the process planning function and adaptive control of the machining operations

The third method is to combine both the experience and hand book recommendations in the selection of machining parameters. Looking through the critical parameters required to be selected for various cutting operations, it was found that a common methodology can be formulated for controlling these operations. However, the various thumb rules and databases can be effectively coordinated through some simple intelligent software.

2.1.1.REQUIREMENTS OF A MACHINING EXPERT SYSTEM

Selection and control of various parameters in different machining operations can be classified in to two major groups, namely off line selection and on line selection. An expert system for machining system should provide selection and control of the various machining parameters under selection mode.

An off line machining expert system selects various parameters required for the initial planning or setting of the machining operations. Critical parameters like tool material, grade, tool geometry, coolant type, cutting speed, feed and depth of cut can be selected for different operations and requirements. For conventional machine tools, these information can be used for manual control of the machine.

On line or real time expert systems provide the key components for factory automation and C.I.M. On line expert

```
 System ──►┌──────────┐      Input   ┌──────────┐   Process output
 Input     │CONTROLLER│────────────► │ PROCESS  │────────────►
           └──────────┘              └──────────┘
                ▲                           ▲
                │                           │
                │                           │
           ┌────┴────────────────────┬──────┴────┐
           │                         │           │
           │    ┌─────────────────────┐          │
           │    │   MODIFICATION      │          │
           │    └─────────────────────┘          │
           │              ▲                       │
           │              │                       │
           │    ┌─────────▼───────────┐           │
           │    │IDENTIFICATION & DECISION│◄───────┘
           │    └─────────────────────┘
           │        EXPERT SYSTEM
           └───────────────────────────┘
```
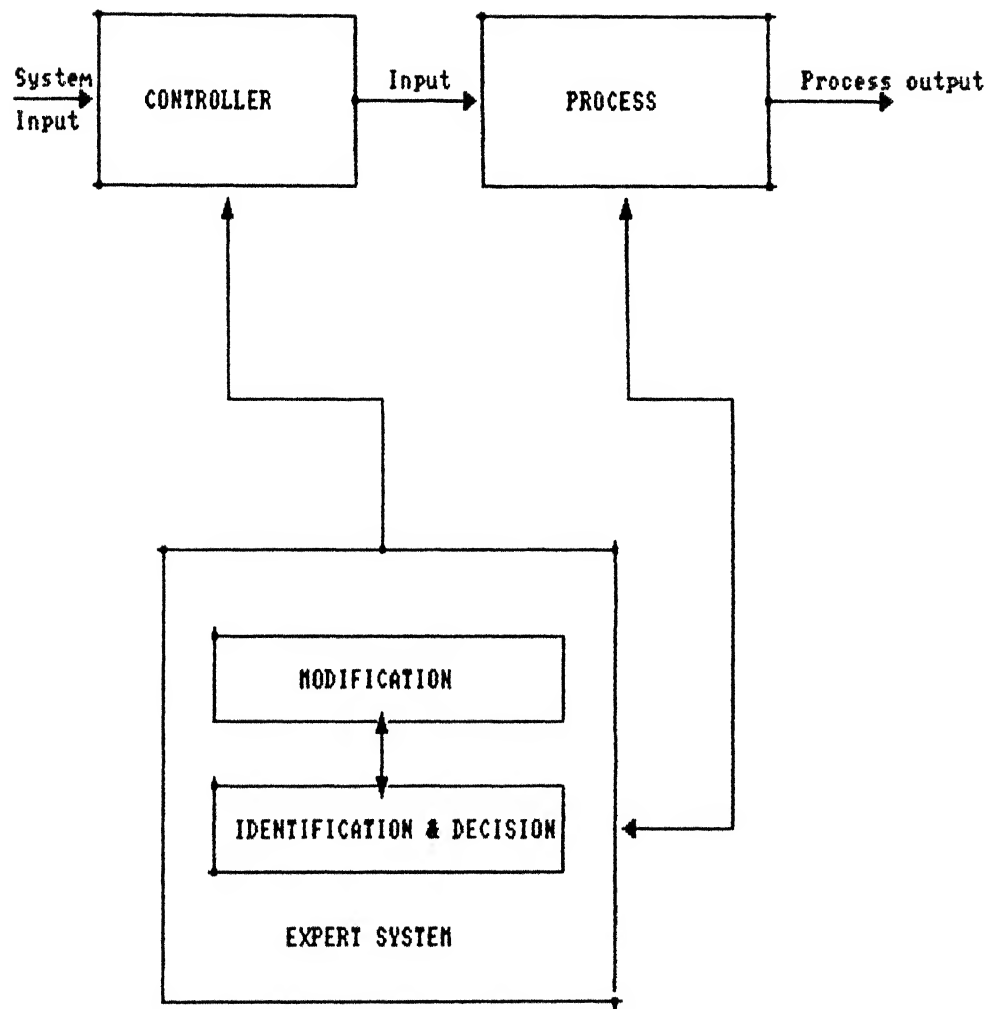
Fig 2.2

On line expert system for process control.

systems operate in a time_varying environment. A real time expert system is designed to compensate for the changing environment by monituring the performance and altering, accordingly some aspects of its control mechanism to achieve optimal or near_optimal performance (fig 2.2)

The process variables like cutting speed, feed rate, depth of cut, hardness of work material, tool wear, and tool tip temperature are measured using suitable sensors either directly or indirectly and fed to the expert system through an analog to digital converter. the expert control system compares variables with the available information in the system and makes the necessary correction for an optimal performance. Like an optimal system or adaptive control system , a performance index can also be added for optimising the variables. This control variable passes through the controller to control the machine.

So the requirements of an expert system for manufacturing processes can be comprehended as below.

1.   There should be provision for off line selection of various critical parameters.

2.   There should be provision for on line selection and controlling of various parameters in real time applications.

SOFTWARE PACKAGE	INTERACTIV- NESS.	NUMERICAL SOFTWARE INTERFACE	SHELLING FACILITY	GRAPHICS & SCREEN CONTROL	HARDWARE CONTROL	STAND ALONE EXECUTABLE PROGRAMS.
VIDHI	POOR	NOT POSSIBLE	TO BE WRITTEN IN LISP	POOR	NOT POSSIBLE	NOT POSSIBLE
PCPLUS	GOOD	NOT POSSIBLE	GOOD	GOOD	NOT POSSIBLE	NOT POSSIBLE
TURBO PROLOG	CAN BE ACHIEVED	POSSIBLE WITH C, FORTRAN.	GOOD	GOOD	NOT POSSIBLE	POSSIBLE

TABLE 2.1.

COMPARISON OF SOME IMPORTANT ATTRIBUTES OF STANDARD EXERT SYSTEM TOOLS.

3.   Expert system should be compatible to computer aided process planning software.

4.   It should be user friendly and portable.

The Table 2.1 gives a comparison between some of the expert system tools on the desirable attributes for the development of a system described above.

Apart from the tabulated attributes, the following points are considered to be critical in the selection of expert system tool for machining operations

1.   The rule base structure of PC PLUS and VIDHI cannot accommodate the vast machining data base efficiently.

2.   Graphical and computer aided process planning interfaces are not easily possible in VIDHI or PC PLUS.

3.   Also, real time control systems cannot be implemented in VIDHI ,PC PLUS, or Prolog.

These reasons put forward the idea of a new expert system tool for machining operations.

2.2. KNOWLEDGE REPRESENTATION

Traditional programs use data structures to store information. High level languages such as Pascal,C use data structures like arrays,records or structures. These data structures are very useful for storing certain types of data; however to represent the kind of complex relationships found in an artificial intelligence program, these structures have several limitations.

Knowledge representation is especially a key to the design of expert systems since it will organise the required information in to such a form that the analysing and decision making will be very much efficient.Knowledge structures are generally composed of both traditional data structures and other complex structures such as logic,frames scripts, production rules or semantic networks.Knowledge structures are usually closely tailored to specific problem areas which are called problem domains.

As mentioned earlier, domain knowledge of most the machining operations is composed with databases, thumb_rules and empirical models. A Frame type of knowledge structure would be the optimum solution for representing database. Thumb_rules and empirical models can be represented easily by Rules.

Knowledge representation Method.	Advantages	Disadvantages
RULES	Good model of human problem solving apparatus. Homogeneous representat--ion. Allows incremental grow--th. Modular representation Easy to implement	Searching time increses exponentially with no of rules. conflict resolution methods should be added Circular rules , dead end IFs etc should be carefully avoided.
FRAMES	More efficient searching for bigger knowledge bases. Good for stereotyped situations. Easy to implement.	Addition and deletion of the frames should be done carefully. Less flexibility.
PROPOSITIONAL LOGIC	Easy to represent the knowledge. Similar to human beings thinking.	Quantifier is not available. Less efficient method
PREDICATE LOGIC	Quantifier is available. It can handle all real world poblems.	Implementation problems
SEMANTIC NETWORKS	Similar to frames. Natural way of represen--tation.	Less flexible.

Table. 2.2

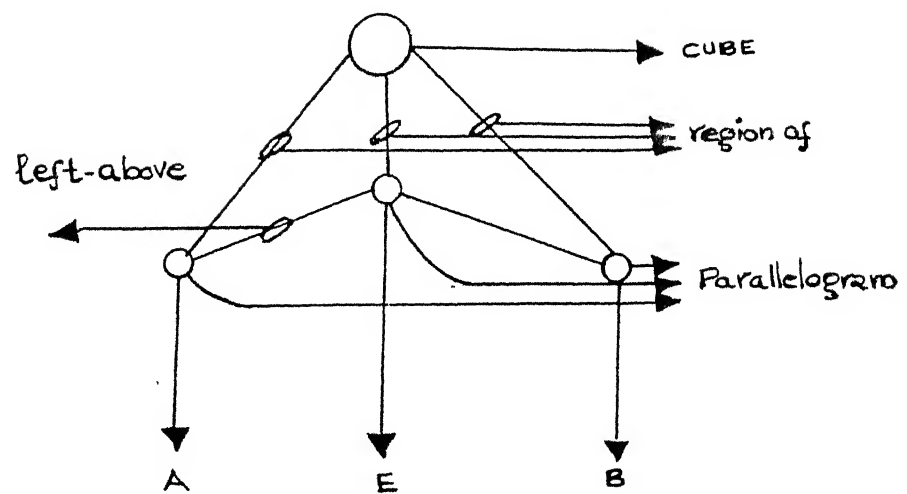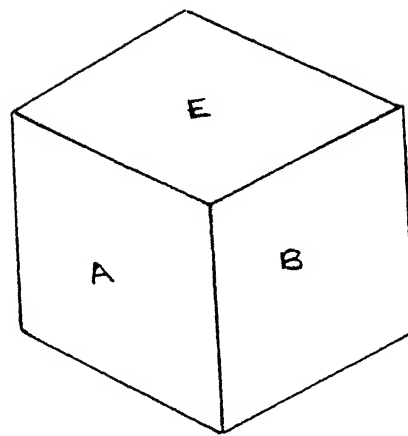Comparison of various knowledge representation methods.

Fig. 2.3

Representation of a cube by Frame

2.2.1. SELECTION OF KNOWLEDGE REPRESENTATION METHODS

Table 2.2 gives a comparative study of some knowledge representation methods. Among the various knowledge representation methods, rules and frames are popular and comparatively easy to implement. As noted earlier, domain knowledge of most of the machining operations is composed of databases and thumb rules. A frame type of knowledge structure would be the best choice for representing a vast and stereotyped database. Thumb rules or empirical relations can be easily represented by IF-THEN rules.

2.2.2. FRAMES

Minsky [15] conceived of "frames", which are complex data structures for representing stereotyped objects,events or situations . A frame has slots for objects and relations that would be appropriate to the situation. Attached to each frame there is information about the usage,default values for slots etc.Frames can also include procedural as well as declarative information. They facilitate expectation_driven processing, reasoning based on seeking confirmation of expectation by filling the slots. Frames organise knowledge in a way that directs attention and facilitate recall and inference. Unlike rules, frames provide a method of organising knowledge into hierarchical structures while retaining a degree of knowledge independence. A simple example of a frame is given in Fig.2.3. The figure

25

represents one view of a cube , as indicated by the IS-A link from the top_level node to CUBE.At the next level,each node describes one face of the cube. The MUST_BE links from those nodes to PARALLELOGRAM describes a constraint on values that can fill the slots represented by the node.

Frames combine the idea of inheritance from object oriented programming with a logic_based specification system. An atom can have not just values but specification under attributes which are called slots. Frames contain slots and fillers. A filler of a slot is has an aspect and a value. The value might be a number or a name of the frame, or more generally a descriptor.

2.2.2.1. Frame structure of XSPERT

The frames designed in the XSPERT are confining to the following syntax.

<frame title>:..... (optional)

<frame name>:........

<slot name> <aspect> <descriptor>

....

....

<inheritance> <frame name>.

Frame name and slot name can be either atoms or list, where the aspect can be any of the logical operators like equal to, less than, greater than, less than or equal to, greater than or equal to, or not equal to. A descriptor contains a description about the slot. The various types of descriptors used are explained in brief below.

Atomic descriptor is the simplest descriptor which is an atom, this can be either a number, name ,definition or some condition.

Rule descriptor is simple rules like <condition1> OR <condition2> OR ..... etc. Using the rule descriptor a number of values or conditions can be attached to a single slot.

Inheritance establishes the relationship between the frames and identifies the top layer frames.

Like any of the classical frame structure, automatic assigning of the default values by the system is also included.

2.3.INFERENCE ENGINE

Frames described above, have a hierarchical structure. To match each of the user input item, whole list of database has to be traversed at each time. This is an inefficient method because

the database list has to traversed linearly. Also matching each item is an independent process, and partial match with one item does not help the matching of another item.

In order to tackle both the issues in searching, a new data structure similar to discrimination net or trie described by Nilsson [16] has been implemented in the present work. developed. In a tree, the data is stored in the nodes in such a way that if data is not found in the node, it is possible to decide in which sub_tree it might be present and hence the search is reduced to that sub tree. In this data structure whole solution path corresponding to each node in the top layer is stored in the form of a list.

Hence directly the child node can be accessed and traversed to the goal, reducing unnecessary exhaustive searching. Also different thumb rules are used to get a realistic solution.

2.3.1.SEARCHING ALGORITHMS

Top layer of the frame is searched breadth_wise using the algorithm given below.

begin

    Go to the frame

        if there is no frame break

check the slots

if matching

    store its inheritance and index value

      in an OPEN list

    if multiple solutions are required

      go to the next frame

      continue

  else

    close the list

    break.

else put error value in the OPEN list

  go to the next frame.

  continue.

end;

Now an initial solution set is formed , which contains the index position of the frame and the inheritance frames , or child_nodes .Corresponding to each child node a solution path is stored in the discrimination net , which is stored separately. So the second set of searching will be as follows.

Get the OPEN list element

  if error value

    go to next element

    continue

  else if nil

break.

else

    open the discrimination net

    store the solution path in a TEMP set.

    continue

Next, search the main database using the TEMP set values and store the s values in a SOLUTION set for printing and display.

2.4. EXPLANATION METHOD

If the user puts WHY for a query the system should show the rule or frame corresponding to that query . The simple algorithm used to implement explanation facility is as follows:

query i

    get the user response.

    if WHY or ?

if i == 1

        SAY_WHY.

    else get (i - 1) query & response

        find the conditions from the database

        if (i - 1) greater than 1

          continue.

    else

        break.

2.6. HEURISTICS

Heuristic or thumb rules as the part of the domain knowledge can be added to get a better approximation to the problem. Various factors can be selected and added according to the domain.

CHAPTER 3

SYSTEM IMPLEMENTATION

Implementation details of the expert system tool XSPERT are discussed in this chapter. Various procedures used for explanation, tracing and heuristic search are also explained in detail.

3.1.SYSTEM ARCHITECTURE

The internal architecture of the XSPERT is given in Fig.3.1. A knowledge base, an inference engine with a parser and a user interface are the three major components in the system.

3.2.SELECTION OF PROGRAMMING LANGUAGE.

LISP and PROLOG are the two most commonly used high_level programming languages for artificial intelligence applications in expert systems, language processing, robotics, and other advanced technologies. Lisp is a programming language designed specifically for symbols and list manipulation rather than numeric data.PROLOG is also a logic_based programming language. PROLOG is a powerful

K N O W L E D G E   B A S E

FRAMES

LAYERED STRUCTURE.

I N F E R E N C E

E N G I N E .

PARSER

Knowledge
acquisition
sub system.

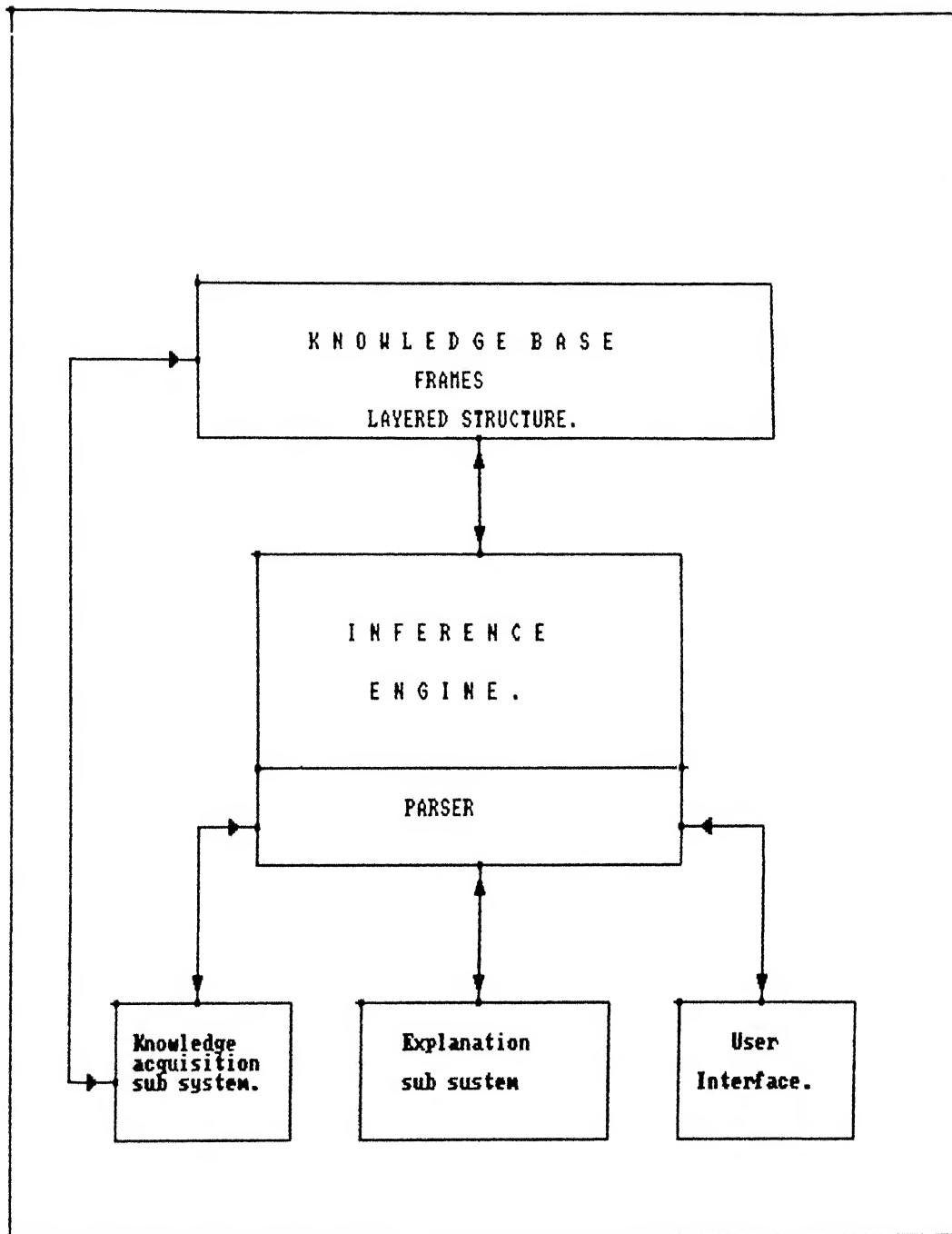Explanation
sub system

User
Interface.

Fig. 3.1

XSPERT ARCHITECTURE.

language that consists of logical relationships expressed in logic_based statements. Prolog has a deeper understanding of the thought process than LISP. Prolog contains a built in database facility and back_tracking facility, both are necessary for many problem solving situations.

While the languages like LISP and PROLOG, used for AI research are excellent for exploration, they are generally ill_suited for general programming. For example Prolog lacks any procedural programming capability _ a deficiency that can make certain tasks ,such as adding numbers to a list, more difficult than they need to be. In addition if we do not need back_tracking or database facilities, they become an extra burden that the application must carry around.

Hence a low level programming language, C is selected for the implementation of XSPERT. C directly deals with addresses, characters and numbers rather than strings or arrays, which makes the programs compact and efficient. C is best suited for graphical interfacing and hardware control applications. Implementation of the expert system tool in C is helpful for further developments in Adaptive control and Computer aided process planning applications.
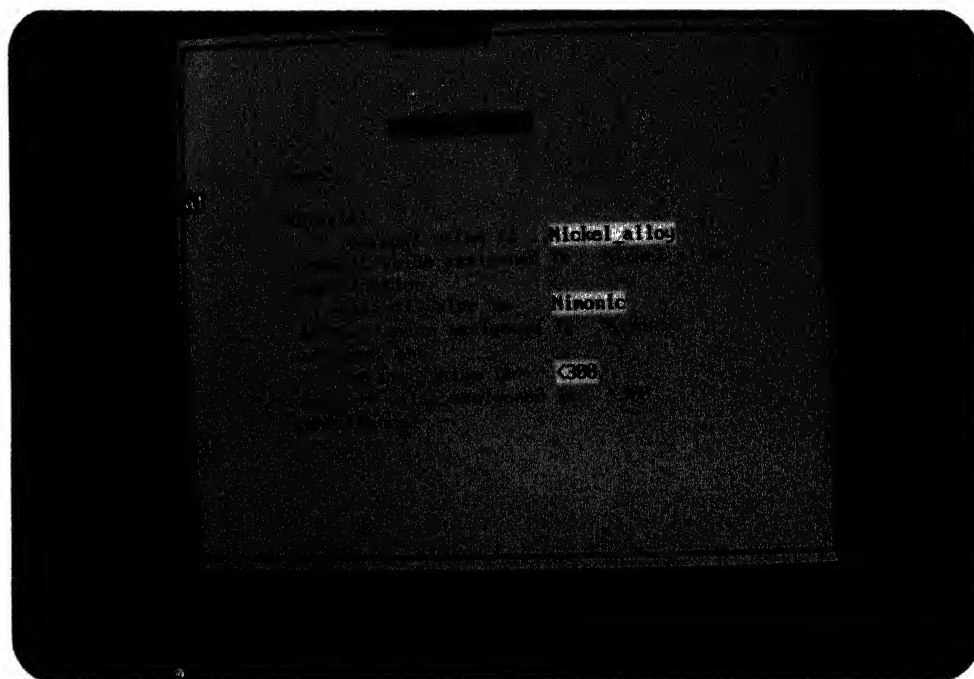
FIGURE 3.2

FRAME STRUCTURE OF XSPERT

3.3. FRAMES

Frames are described in XSPERT as given in the figure (Fig .3.2) On the top of the frame an optional layer name is displayed. Current frame name is displayed in the next line. Frame name ca· be either an atom or a list. Slot names, corresponding values and default values if any ,are showed next in the frame. Presently number of slots in a frame are fixed and limited to five. However, this can be easily modified according to the user's requirements. The slot values can be atoms or lists,simple rules like <cond1> OR <cond2>...,or numeric values like >100, =120,<200.05 .The rules are to entered in the form of conditions, viz, condn1^condn2^condn3.....In order to simplify the data entry, a,#,! are used to represent less than or equal to,greater than or equal to, and not equal to conditions. Any numeric value should be prefixed by any one of the symbols like =,<,>,a,#,!. Last slot contains the inheritance status and it can be a frame name or "end" to identify the top most layer.

When the frames are stored, automatically an index list is formed with relative positions of different frames. Using these index list, a discrimination list is formed for each frame in the top layer. This discrimination list contains the solution path up to the last node for all top layer frames. Unlike in conventional discrimination nets ,here the solution path is stored separately from the main structure.

3.4.INFERENCE ENGINE

Once the query session is over the input values are stored in a query_list and these are used by the inference engine for the first phase of searching operation. In the first phase, the top layer frames are compared with the query_list. There is a smart parser which does the parsing of slot values for rules, numerals and inequalities. It breaks the complex slot entry into small atoms for the smooth verification of matching. Numeric values are compared and verified as per the type of inequality used in the particular slot. If there is a solution it is stored in a t mporary solution list. Otherwise it goes to the error_message routines. Using the temporary list the inference engine goes to the discrimination set.

Temporary solution set stores the absolute index position of the top layer frame where the matching was successful and the corresponding child node. Using this child node, inference engine will start the second phase of searching operation. At first the discrimination net is opened and the child node of the temporary solution set is compared with the discrimination net entries of same layer. If there is a matching entry ,corresponding frame position is temporarily stored in position_list and inference process moves to the next phase. It checks the initial query list for unused user inputs. If the list is not empty same matching
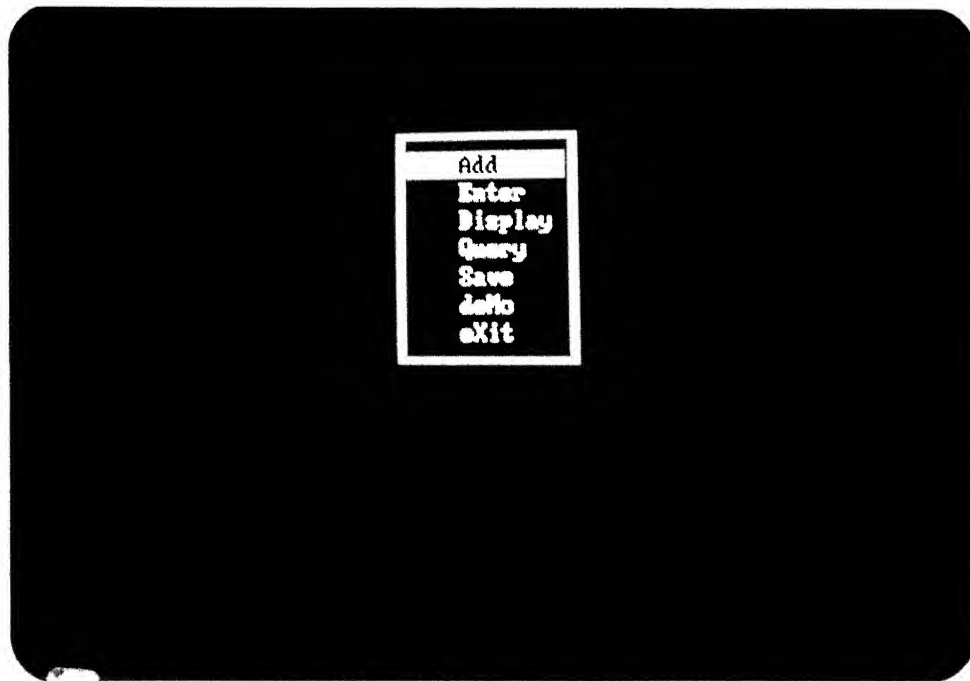
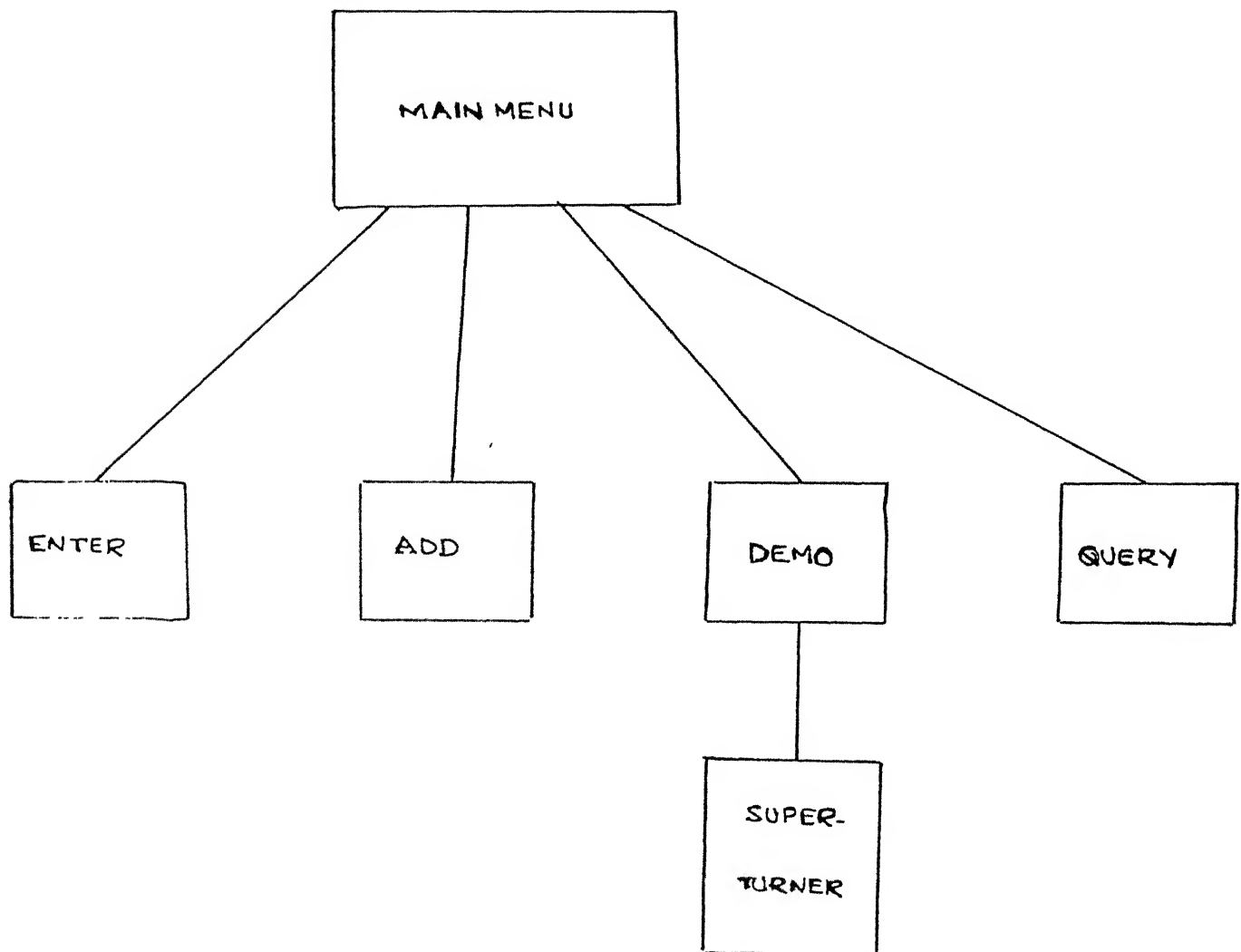FIGURE 3.3

MAIN MENU OF XSPERT.

Fig. 3·4

MENU STRUCTURE OF XSPERT

process is done with the frame corresponding to the temporary solution list If the query_list is empty, inference engine stores the position of the solution nodes till the last node in the position_set and closes the discrimination set. In the next phase, according to the position in the position_set, frames and corresponding slots are stored in a solution_set for final output.

If the user input is '?' or WHY for a query, the explanation routines are automatically invoked. Using the algorithm given in Chapter.2 ,the system gives a simple explanation which is sufficient for the present query mode, since the query session is relatively short.

Like any popular expert tool tracing facility is also incorporated in XSPERT. The user can select his option for trace from the pop_up menu.

3.5. MENU SYSTEM

The software is totally controlled by menus and windows. XSPERT starts with a message window and a MAIN MENU (Fig.3.3). The MAIN MENU lists various options which again lead to sub_menus or windows. Figure 3.4 shows the complete structure of the menus. The pop_up menu options can be selected with the help of UP and DOWN arrow keys (of the numerical key pad of the IBM83 keyboard or an equivalent one) or pressing the hot key mentioned as the capital

```
please enter the title name:drilling

 FRAME MEMBER <FIRST>   :..name

FRAME MEMBER <SECOND> material

DEFAULT VALUE <SECOND>:.steel

 FRAME MEMBER <THIRD>   :..speifiatioc

 DEFAULT VALUE <THIRD>  :...aisi1200

 FRAME MEMBER <FORTH>   :..hardness

 DEFAULT VALUE <FORTH>  :..<230

 FRAME MEMBER <FIFTH>   :..inheritance1
```

FIGURE 3.5

ENTER MODE OF XSPERT.

letter in each choice. The selection is being highlighted by reverse video imitating a big cursor. the selection of the option is done by pressing ENTER key or the HOT key.

Selection of the ENTER mode option opens the enter mode window (Fig 3.5) for making a new expert system. User can enter various frame names and slot values. If the user wants to enter data ,he can start it by selecting the option from the menu. After the data entry user can go to the MAIN menu and select the SAVE file to save the work.

By selecting ADD mode, user can either add data to an existing data base or start a new system with the same frames.Later he can save the work by selecting SAVE from the main menu.

In DISPLAY mode the frames are displayed according to the sequence for the verification.

QUERY mode starts with a query window, asks the user about the details about the domain or frame file name and various queries as per the instruction. User can select TRACE on or off from the pop_up menu. The solution will be displayed in a solution window.

Windows can be moved and resized by pressing the arrow keys.

All the routines including windows and menu are written in Microsoft C for fast and efficient execution.

CHAPTER 4

EXAMPLES

In this chapter details about an expert system developed by XSPERT is d scussed. Also the methodology adopted for selecting various parameters in different conditions are also discussed.

The domain of the expert system has been selected as the machining of super alloys, which creates enormous difficulties to the industries. An expert system for the turning operation of super alloys, SUPER_TURNER is created using XSPERT. Various problems encountered in the machining of super alloys are described below.

4.1.PROBLEMS OF MACHINING OF SUPER ALLOYS

Super alloys namely, nickel base alloys, heat resistant alloys and titanium alloys are used for the majority of components in aerospace industries. Machining of these materials pose a serious problem all over the world. High hardness, strain hardening nature, and excessive heat generation during the machining are some of the major difficulties in the machining

process. Hence selection of proper material and grade of tool material is very important for the process. Depending upon the nature, properties and composition of the work material various parameters like tool material , type of tool,tool material grade, tool geometry ,type of coolant special instructions etc are to be selected very carefully .Only an experienced production engineer can do such a difficult task

Titanium alloys are among the most troublesome materials to machine at practical cutting conditions. The greatest difficulty in machining these alloys stems from the very high cutting temperature experienced under conditions, that are ordinary for most other materials. The high tool temperature experienced when machining titanium is attributed to the very low thermal conductivity.[16]

Nickel is a member of Platinum group in the periodic table. Nickel_base alloys are relatively difficult to machine because of high tool tip temperature. This is not due to unusual strength or hardness.

Heat resistant alloys or space age alloys also pose a major problem in metal cutting area. Very poor performance of even high grade tools, unsatisfactory dimensional accuracy due to the sudden tool wear and breakage are some of the common problems. This is mainly due to the following problems. Low thermal conductivity and

specific heat gives a very high cutting temperature which causes the sudden and frequent tool failures. Strong tendency of some of the work materials to weld to the tool tip and make a built up edge causes attritious wear. Low value of Young's modulus also creates difficulties in machining.

4.2. DESIGN METHODOLOGY FOR SUPER_TURNER

Research works done by various aerospace industries and Met_cut Research Inc.[18] are used for the domain knowledge of the SUPER_TURNER. Research and testing reports of Development of machining technology group of Gas turbine research establishment,Bangalore [19] are also used for the domain knowledge and thumb rules.

4.2.1. TOOL MATERIAL SELECTION.

Tool material for each type of work material is to be selected properly for the optimum machining conditions. As mentioned in Chapter 2 ,some of the most important factors to be considered for the tool selection are given below.

Relative hardness of tool material

Relative hardness of the tool material should be at least three to four times than of the work material. But it has been

found that, in the case of super alloys, hardness of work material may not be the major criterion for the selection of tool material. Some alloys behave abnormally even at a lower hardness. Hence data obtained from related industries should be the right choice for the selection.

Presence of Abrasive particles in the work

Abrasive particles in the work or in the work surface like scales inclusions may be another factor for tool selection. If the work material is clean and free from any sort of inclusions, a standard tool material can be selected. But in most of the cases in industries, work material may not be pure like in the standard test conditions. In that case either a better tool material has to be selected or necessary adjustments should be done in the cutting parameters.

Machine tool condition

Condition of the machine is also plays a major factor in the tool selection. Rigidity of the machine, maximum and minimum speeds, horse power etc will influence the tool selection. In order to increase the productivity, industries started using more refractory tool materials. At the same time, such a development calls for an increase in machine tool horse power and rigidity. Hence as a thumb rule, under the following conditions a more

Sl no	Symbol	Category	Designation	Cutting Conditions.
1	P	Ferrous metals with long chips	P01, P10, P20 P30, P40, P50	
2	M	Intermediate.	M10, M20 M30, M40	
3	K	Non ferrous metals and ferrous metals with short chips.	K01, K10, K20 K30, K40.	

Table 4.1

ISO classification of carbides

ductile tool material like High speed steel are to be included.

If the machine is older and less rigid.

If the machine is under powered .

If the maximum spindle speed is comparatively low.

4.2.2. TOOL GRADE SELECTION

Selection of the tool grade is done according to the Table.4.1 As per the ISO classification, carbides are classified into three major categories as P type, M type, K type. Normally P type is suitable for ferrous materials which produce long and curly chips. P type has got better ability to resist crater wear. On the other hand, K type is best suited for nonferrous metals and ferrous metals with short chips. Normally K type carbides are used for super alloys ,nickel base and titanium alloys. Moving from P type to K type the feed rate should be increased at the same time cutting speed should be reduced for better performance.

4.2.3. TOOL LIFE CALCULATION.

Tool life is a highly complex parameter ,which influences the over all performance of the machining operation. Taylor's equation

$$V\ T^{n}\ =\ K \qquad\qquad (4.1)$$

is one of the earliest mathematical model developed to determine

the tool life T in terms of cutting speed V and constants n & K. But the value of n was found highly fluctuated from experiment to experiment.[14] because a lot of parameters influence the performance of the tool. Some of the major parameters are explained below.

Sharpness of the tool is a major factor affecting the performance of the tool. A blunt tool may fail fast due to the impruper cutting action, excess heat generation and formation of built up edge. Normal practice is to give a small radius to the tool tip for an optimum performance.

Machine condition is another major parameter affecting the tool life. Rigidity and capacity of tool work system to store elastic energy are very much important for better tool life. Chatter and vibration of the tool_work system may cause incipient failure of the tool.

Proper tool geometry is also very much important for a better tool life and performance. Proper selection of the tool angles namely rake angles, clearance angles, cutting angles influence the crater wear and flank wear of the tool.

Material characterstics also plays an important role in the tool life and performance. Material hardness ,type and shape of the inclusions, various elements present in the material etc

$\propto b$ Back rake angle

$\propto s$ Side rake angle

θe End relief angle

θs Side relief angle

Ce End cutting angle

Cs Side cutting angle
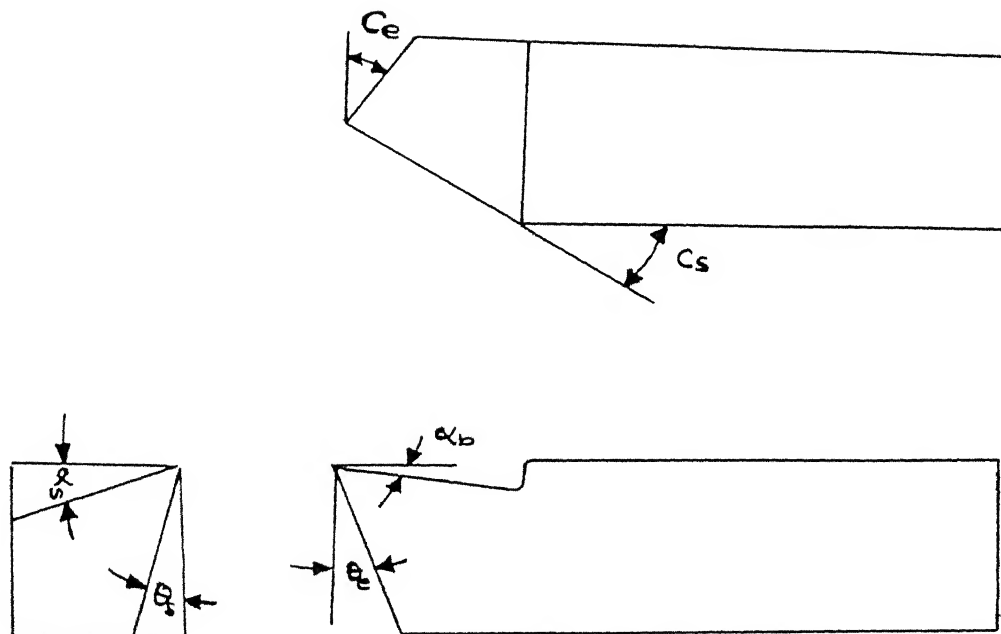
Fig. 4.1

Tool geometry of a single point tool

TURNING	MILLING	DRILLING
SIDE RAKE ANGLE	SIDE RAKE ANGLE	RADIAL RAKE ANGLE
BACK RAKE ANGLE	AXIAL RAKE ANGLE	HELIX ANGLE
SIDE CUTTING ANGLE	CORNER ANGLE	1/2 POINT ANGLE

Table 4.2

Comparison of tool angles for various cutting tools

influence the tool life.

4.2.4. TOOL GEOMETRY SELECTION

Geometry of a tool is defined by the various tool angles (Fig.4.1). They are back rake angle, side rake angle, side cutting angle, end cutting angle, side clearance angle, end clearance angle. A comparison of the tool geometry for various machining operation is given in Table 4.2. Proper tool geometry is very important for better tool life and performance. Crater wear and flank wear can be controlled by adjusting various tool angles.

4.3. OPERATIONAL DETAILS

Expert system SUPER_TURNER starts by choosing the demo mode from the main menu. The query session is not very big and it will ask about the

    type of work material
    material specification
    work hardness

The next phase of query user has to select the option from a menus (Fig 4.2 to 4.6). In this session, user can select
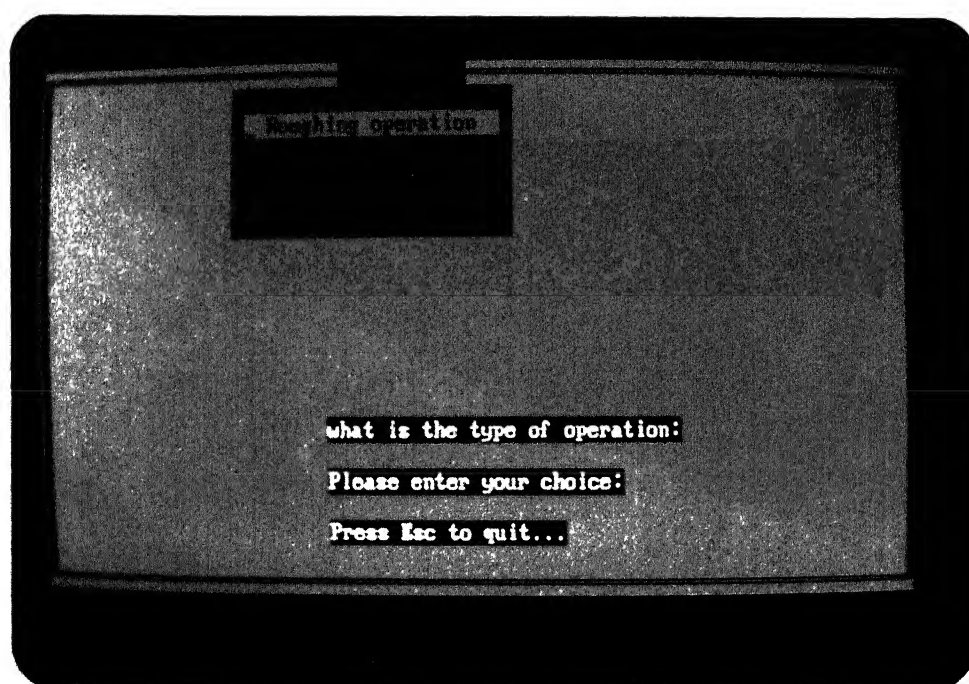the nature of material like
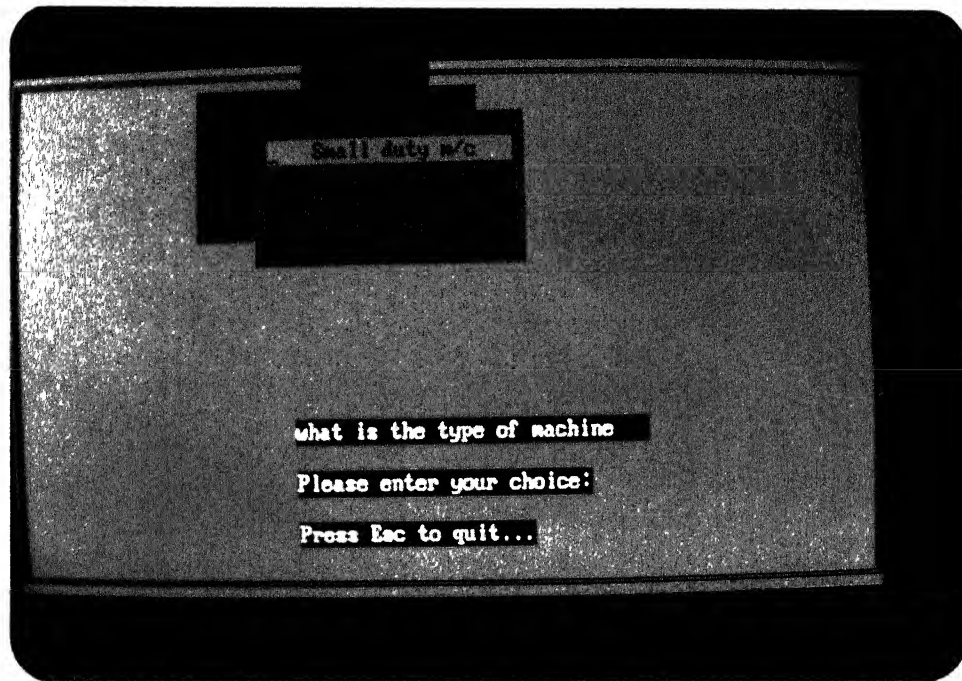
FIGURE 4.2

QUERY MODE OPTIONS FOR SUPER_TURNER

FIGURE 4.3
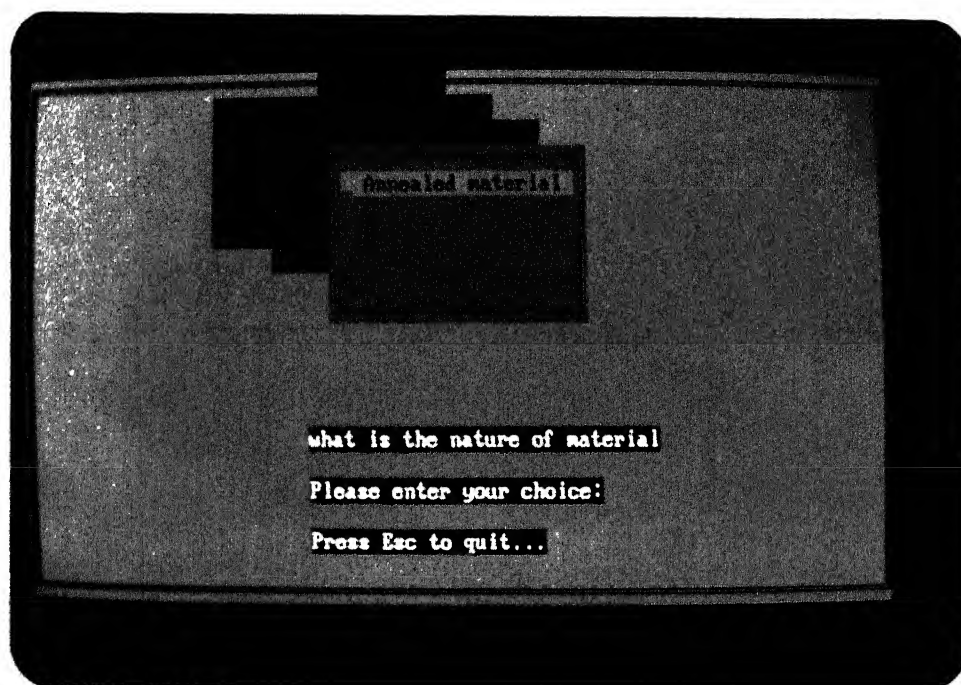
QUERY MODE OPTIONS FOR SUPER_TURNER

FIGURE 4.4

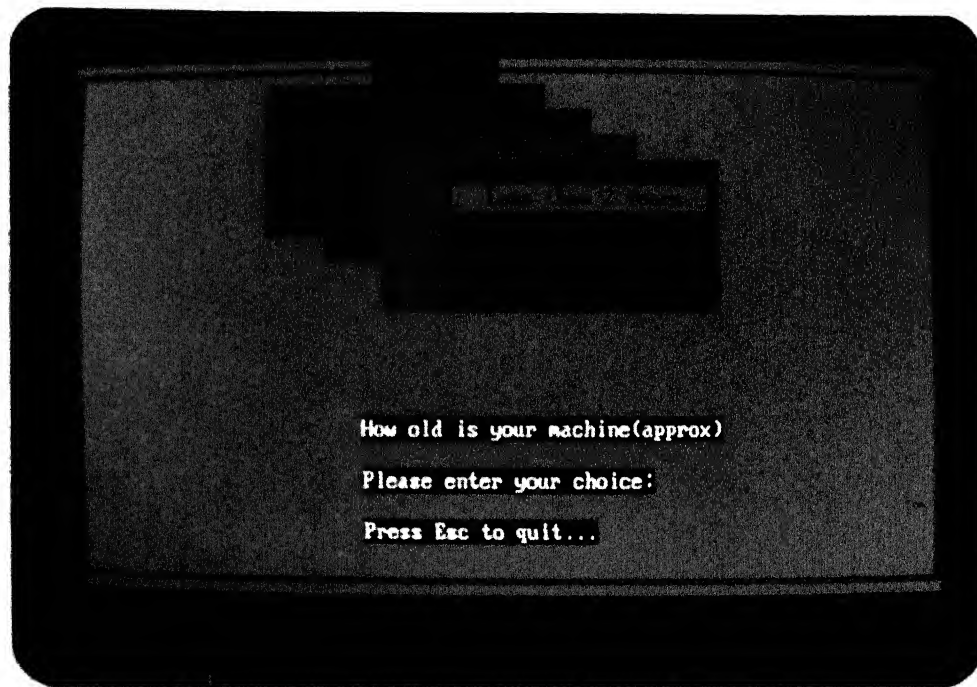QUERY MODE OPTIONS FOR SUPER_TURNER

FIGURE 4.5

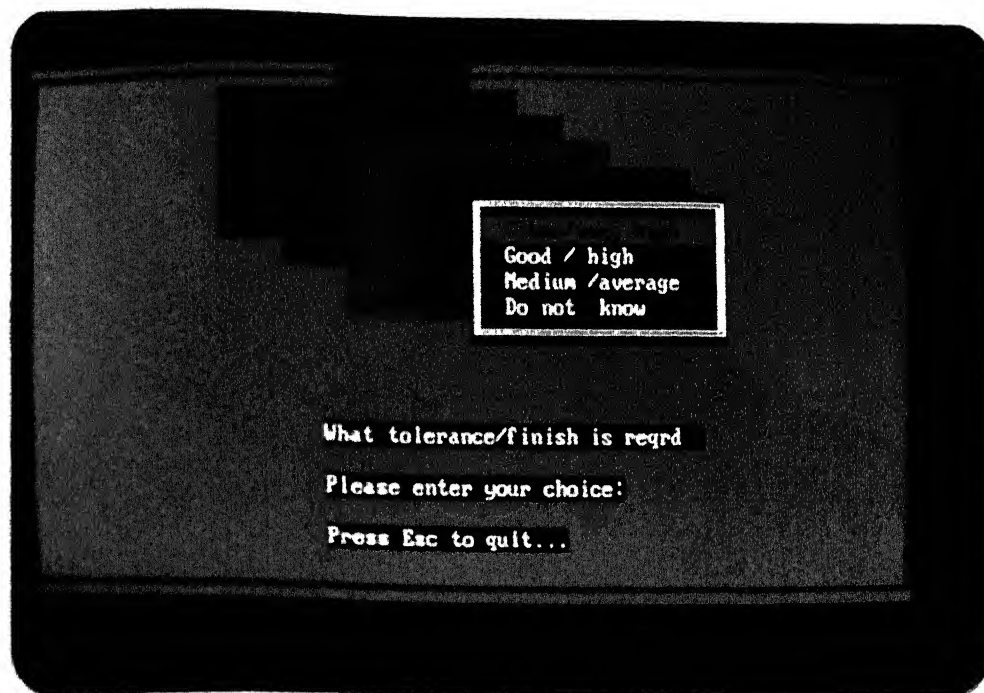QUERY MODE OPTIONS FOR SUPER_TURNER

FIGURE 4.6

QUERY MODE OPTIONS FOR SUPER_TUNER

ANNEALED

HARDENED

GUENCHED

NONE OF THESE

DO NOT KNOW

from the pop_up menu.

Similarly the system asks about the nature of machine which is going to be used for the operation,

LIGHT DUTY MACHINE

MEDIUM DUTY MACHINE

HEAVY DUTY MACHINE

DO NOT KNOW

System assumes about the rigidity and accuracy of the machine from the following query. It asks indirectly about the age of the machine since the age of the machine and factors like accuracy, rigidity are directly related. User can select

LESS THAN 3 YEARS

LESS THAN 6 YEARS

GREATER THAN 6 YEARS

DO NOT KNOW

Next type of operation like roughing or finishing should be selected from the menu .

Accuracy and surface finish requirement are to be selected from the menu next.

VERY GOOD FINISH/CLOSE TOLERANCE

MEDIUM

AVERAGE/OPEN TOLERANCE

DO NOT KNOW

User has the freedom to opt "do not know" or "none of these". In that case system chooses an approximate value and do the necessary calculations.

Next, the system selects the required tool material, tool grade, coolant type, tool geometry, cutting speed, feed rate and depth of cut for the given constraints. Solution and the recommendations are displayed in the form of solution windows. (Fig 4.7 & 4.8).

Output result format is as given below.

Tool material   ....

Grade/specification   :.............

Type of tool   ....

Feed rate <mm/min>   ....

Cutting speed   ....

Depth of cut <mm>   ....

Tool geometry   ....

Coolant type   ....
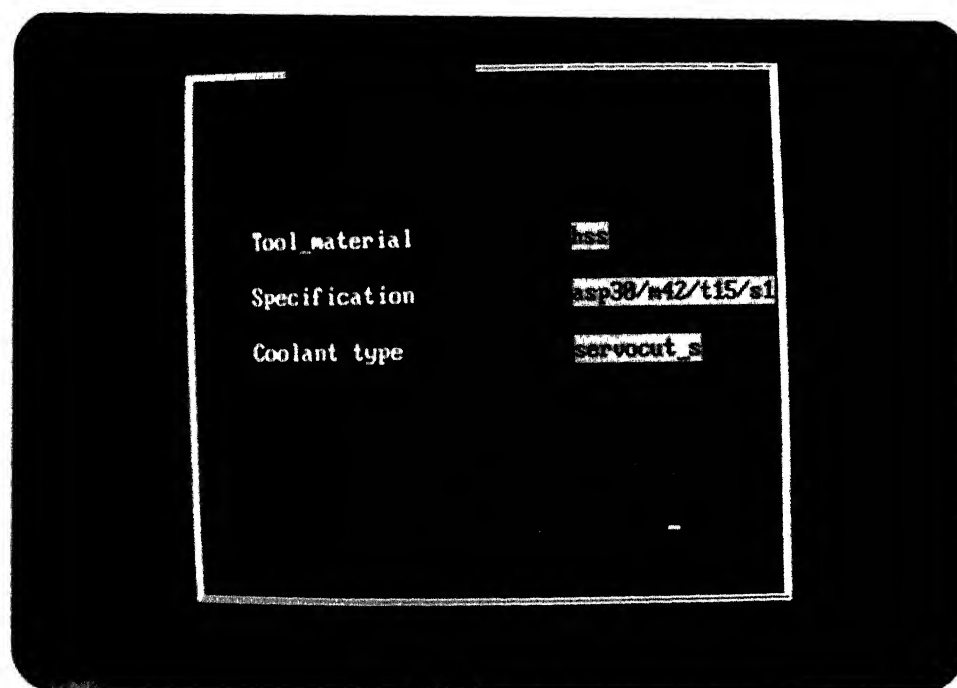
Remarks <if any>   ....

FIGURE 4.7

SOLUTION WINDOW OF XSPERT

FIGURE 4.8

SOLUTION WINDOW OF XSPERT

digital converter. Simulation of the real time control operation is also included in DEMO mode.

In order to make the query session more interesting and helpful to the user, a simple explanation facility is incorporated. An option to check the whole searching operation is also attached using the trace menu.

An expert system for the turning operation of super alloys is developed using the present work. Various parameters like tool material, grade, tool geometry, cutting parameters and type of coolant for different aerospace materials can be selected using this expert system

Menus and windows are used extensively to make the system attractive and user friendly. A help menu is also included to guide the user properly.

5.2. SCOPE FOR FURTHER WORK

Frames implemented in the present work can handle only atoms, lists or simple OR rules. A method for evaluating complicated rules ,data or user defined functions will be useful to make a flexible system. Presently ,number of slots in the frame is fixed In order to bring in more flexibility into the system, it would be desirable to build in capabilities for interactively changing the

number of slots.

In query session, system cannot handle or recognise equivalent words or expressions. By incorporating natural language processing methods, the query session can be made more intelligent and natural. Explanation method can be modified by implementing better algorithms for an interesting query session.

System can be made flexible by incorporating suitable methods to change the uncertainty conditions or thumb rules interactively. Same system can be modified as a general expert system tool by this method.

Finally graphical interfacing for pictorial representation and consultation can used for a wider range of applications in engineering like computer aided design or process planning. Facility to interface with adaptive control sensors with analog to digital converters is a useful step towards total automation.

REFERENCES

1. Armerego E.J.A., and Brown.R.H, *The machining of metals*, Prentice Hall, Englewood Cliffs, 1969

2. Kronenberg M., *Machining science and applications*, Pergamon Press, 1960.

3. Chao B.T. and Trigger K.J., Temparature distribution at tool_chip and tool work interfaces in metal cutting, Trans *ASME*, Vol 77, pp 1107 -1121, 1955.

4. Shaw M.C., *Metal cutting principles*, MIT press, Cambridge, 1984.

5. Bhattacharya A., *Metal cutting,principles and practise*,Central Book publishers, Calcutta, 1984.

6. Ernst H., and Merchant M.C., Chip formation, friction & finishing *Trans. ASME*, 1941, pp 365.

7. Lee E.H., and Shaffer B.W.,*Trans.ASME*, 1951.

8. Chang T.C. and Wyask R.A., *An introduction to automated process planning systems*, Prentice Hall International Inc, 1985.

9. Evershein W., Konig W., Schwanby W., Weshch H., Computer aided planning and optimisation of data, CIRP Vol 30/1/81, pp 409-411

10. Ginsti F., Santoch M., Gini D., COATS, an expert system for optimal tool selection, CIRP Vol 37/1/1987.

11. Boerma J.R., Kals H.J.J., FIXES, a system for automatic selection of set_up and design of fixtures, CIRP Vol 37/1/1987 pp 87-90.

12. Van't Evve A.H., Kals H.J.J., XPLANE, a generic computer aided process planning system for parts manufacturing, *CIRP* Vol 35/1/1986, pp 325-329.

13. Anbarasu P., Design and implemetation of an expert system for surface grinding, *M.Tech thesis report*, I.I.T Kanpur,1989.

14. Srinivasa Rao V., Computer aided process planning for surface grinding, *M.Tech thesis report*, I.I.T.Kanpur, 1989

15. Minsky, Marvin., A framework for representing knowledge, *The psychology of computer vision*, pp211-276.1972

16. Nilsson V., *Principles of artificial intelligence.*,pp 210.

17. Jack.R.Marsh, *Machining of super alloys*, American society for metals, 1962.

18. Metcut Reasearch Associates Inc, *Machining data handbook* Vol I & II, 3rd edition ,1980.

19. Developmant of machining technology group, Gas Turbine Research Establishment, Bangalore, *Various internal machining test reports.*

APPENDIX A

USER'S MANUAL

This user's manual gives the user a comprehensive guide to the system, XSPERT, delineating various steps encountered during usage. As the system is completely menu driven, the utilisation of the system is stated here in terms of the individual menus.

The system operates on MSDOS Version 2.0 or later and occupies a total memory of nearly 64 K. A working memory of 5 K is also needed for making index files and discrimination sets.

The system starts with a message window. By pressing any key, it goes to the MAIN MENU. Various options like ENTER, ADD, DISPLAY, QUERY, DEMO, SAVE and EXIT are shown in the main menu. A menu option is selected by moving the cursor to the option and pressing the <RETURN> or <ENTER>. The cursor movement is achieved by UP_DOWN keys, SPACE BAR, or HOT keys given in the menu as capital letters.

Selecting the enter option creates an ENTER WINDOW on the screen, which asks the user about frame name, slot name and default values. The information can be saved in suitable files. User can go to the main menu or start enetering data then.

Selecting ADD option creates a window for adding information to an existing knowledge base or a new one. The specific format for entering rules to the slot values are given below.

A simple rule like

IF material1 OR material 2 OR material 3.....

is to be entered as

material 1 ^ material 2 ^ material3 ....

Similarly "!", "@", "#" are used to represent NOT EQUAL TO, LESS THAN OR EQUAL TO and GREATER THAN OR EQUAL TO respectively. All the numeric values should start with any of the symbols like "=", "<", ">", "!", "@" or "#".

The query option starts the consultation of the system. After entering proper frame name, system asks various questions related to the problem. Necessary information can be entered in the query window. There is an option to know the reason by entering "why" or "?".

The DEMo mode starts the demo expert system, SUPER_TURNER, developed for the machining of super alloys. Most of the query in this demo mode is in the form of pop_up menus. After selecting proper values, the system opens a solution window to suggest the necessary recommendations. There is an option to simulate the real time expert system also .

Any time, the system returns to the main menu by pressing the
<ESCAPE> key.